DYNAMIC MODELING FOR CONSTRUCTION INNOVATION

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ABSTRACT

Previous research on construction innovation has commonly recognized the importance of organizational climate and key individuals, often called “champions”, to the success of innovation. However, it rarely focuses on the role of project participants at the project level and addresses the dynamics of construction innovation. This paper therefore presents a dynamic innovation model that has been developed using the concept of system dynamics. The model incorporates the influence of several individual and situational factors and highlights two critical elements that drive construction innovations: 1) normative pressure created by project managers through their championing behavior, and 2) instrumental motivation of team members facilitated by supportive organizational climate. The model is qualified empirically using the survey results conducted with project managers and their project team members working for general contractors in Singapore, by assessing causal relationships for key model variables. Finally, the paper discusses the implications of the model structure to foster construction innovations.

Keywords: construction, dynamics, innovation, motivation, managers, organization, projects

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INTRODUCTION

Construction projects tend to generate novel and complex problems that often require innovative solutions (Nam and Tatum 1992a). Furthermore, as project owners become more sophisticated in terms of product needs and requirements, innovation becomes essential to the success of a construction project. Innovation also creates possibilities of achieving competitive advantages for the construction company (Slaughter 1998; Pries and Janszen 1995). However, the construction industry is known to have many barriers and resistance to innovations.

To address these issues significant research efforts have been made in the past. Previous research on construction innovation has mainly emphasized the organizational aspect at the company level (Laborde and Sanvido 1994; Tatum 1989, 1987) and indicated that an organizational climate that is supportive to innovation can foster innovation (Tatum 1986, 1989) by overcoming barriers to construction innovations. Moreover, organizations need enthusiastic and committed individuals, often called “champions”, in the innovation process (Nam and Tatum 1992a, 1997; Winch 1998; Tatum 1986).

Despite a number of innovation-related research in the past, there is lack of understanding on how project participants such as Project Managers (PMs) and project team members interact in a construction project environment to facilitate innovation. In addition, previous research rarely addressed innovation as a dynamic process. As emphasized by Kanter (1988) and demonstrated by the work of Repenning (2002), innovation is complex and dynamic, for which reason a dynamic approach is needed to effectively model the major tasks involved in the process.

This paper presents a conceptual dynamic innovation model developed using the concept of system dynamics (SD). Focusing on the dynamic innovation process at the project level, the model attempts to address several questions:

- What is the motivation behind innovation?
- What makes the innovation process dynamic?
- What are the individual, situational, and behavioral factors that are important for innovation?
- And in what ways can organizations foster innovation?

All of these research questions are incorporated into the SD model. To give more reality to the model structure, causal relationships for key model variables are assessed, using the survey results conducted with PMs and project team members working for general contractors in Singapore. The rest of the paper is organized as follows. Following a brief introduction on common terminologies used in the research and the research methodology, we describe the dynamic innovation model. Then, we discuss the model qualification process followed by the model discussions and implications.

DEFINITIONS

Innovation

Based on the definitions in the literature (Zaltman et al. 1973; Rogers 1983; Van de Ven 1986; Damanpour 1991), this paper defines innovation as the generation, development, and implementation of ideas that are new to an organization and have practical or commercial benefits. The term ‘innovation’ also encompasses adoption and implementation of products or processes developed outside the organization.

Champions and Championing Behavior

Construction is a project-based process. Accordingly, the role of champions can be different from that in a production process in other types of organizations (Tatum 1989). This paper posits that the role of the PM is essentially that of a champion to promote the creation, adoption, and implementation of new ideas in the construction project environment. It is further argued that PMs’ championing is manifested in their championing behavior, which is defined as the PMs’ observable actions directed toward seeking, stimulating, supporting, carrying, and promoting innovation in the project. PMs may contribute to all or some of the following tasks:

- Coordinate and combine the creativeness of project team members and facilitate their idea generation efforts
- Convince and sell innovative ideas to potential allies, and get support and approval from them
- Integrate information and encourage individuals to work together to generate new ideas
- Adopt and implement new ideas on projects

Organizational Climate for Innovation

‘Organizational Climate for Innovation’ represents the cognitive interpretation of an organizational situation perceived by individuals and the signals that they receive concerning organizational expectations for innovative behavior and potential outcomes of the behavior

(James et al. 1990; James and Sells 1981, Scott and Bruce 1994). In this paper, organizational climate for innovation is conceptualized by two basic dimensions, namely, resource supply and support for innovation.

RESEARCH METHODOLOGY

This research uses the concept of SD that uses causal loop diagrams to develop the qualitative innovation model. The causal relationships for key variables in the conceptual model are assessed using correlation analysis, the detailed description of which is later presented in the model qualification section in the present paper.

System Dynamics

SD has been widely used to analyze industrial, economic, social, and environmental systems of all kinds since it was first developed to apply control theory to the analysis of industrial systems in the late 1950's (Turek 1995). One of the most powerful features of SD lies in its capability to provide an analytic solution for complex and non-linear systems (Kwak 1995). Also, SD models are either quantitative or qualitative. In quantitative SD models, a given problem or system is analyzed by simulating model structures, which contain quantitative values. However, a qualitative model can be more appropriate when there is a high level of uncertainty and doubt about the values of the model parameters (Coyle 2000).

In this paper, we use the qualitative modeling approach. Instead of undertaking model simulations, a purely qualitative model uses casual loop diagrams to analyze problems and provide policy guidelines. Causal loop diagrams in the model describe conceptual model structures derived from a modeler's understanding of the system and show the dynamics of variables involved in the system (refer to Table 1 for typical denotations used in a causal loop diagramming). For example, Fig. 1 represents the causal relationships between construction progress and schedule pressure. Appropriate schedule pressure can increase productivity, which can facilitate the construction progress. At the same time, higher schedule pressure can also slow down the construction progress by lowering the work quality. Once increased or decreased, the construction progress consecutively affects the schedule pressure by forming feedback loops.

<< Insert Table 1 about here >>

<< Insert Fig. 1 about here >>

DYNAMIC INNOVATION MODEL

Innovation in construction project is arguably initiated to address challenges or problems encountered at work, and to explore opportunities for improvement in order to meet project objectives or improve performance. Depending upon a project performance, an innovation mechanism can be explained in terms of purely behavioral dimension — i.e., through motivation. In addition, there are several individual and situational factors that influence innovation during project execution. The dynamic innovation model presented below systematically takes into consideration these factors accompanied by other behavioral and dynamic features involved in a construction project.

Model Description

Construction innovations may be primarily driven by two different sources of motivation: PM and team members. As diagrammed in Fig. 2, PM-driven motivation is initiated by the project performance gap between the desired performance and the actual performance. A bigger performance gap leads to a higher PM-driven motivation. For example, significantly delayed construction schedule will make a PM look for new methods to improve schedule performance. PM-driven motivation is then reflected in PM's championing behavior, which can influence construction innovations in three ways.

First, PM forces team members to increase their innovative efforts (B1). This would arise when team members were harvesting and protecting existing practices and not paying attention to develop new ideas to address project challenges. In this situation, as indicated by Van de Ven (1986), PM could act as a pressure agent to trigger the action thresholds of team members and manage their attention toward innovation. Second, a PM facilitates idea generation among team members (B2). This would mean a PM could encourage and promote generation of new ideas by motivating and inspiring team members. Third, a PM's championing directly facilitates the implementation of ideas. This could stem from the fact that special effort on the part of a PM is needed for the judicious implementation of internally generated and/or imitated ideas on project. All these championing roles could increase the level of innovation.

Since construction companies have full control of process innovation (Laborde and Sanvido 1994), innovative practices, if properly managed, can be expected to increase the efficiency and effectiveness of construction operations, thereby enabling project team to meet project objectives or outcomes. This would mean that the increased level of innovation on project would reduce the project performance gap by improving the project performance. As a result, the associated feedback loops B1, B2 and B3, as shown in Fig. 2, tend to balance the system.

<< Insert Fig. 2 about here >>

Meanwhile, Fig. 3 explains how team member-driven motivation works. Project performance determines the level of team members' motivation as well as the PM-driven motivation. However, unlike the PM-driven motivation, team member-driven motivation tends to increase when the actual performance is better than the planned performance, because project team members can devote more time to issues not urgently required. Once initiated, team member-driven motivation keeps increasing due to the self-reinforcing loop denoted as R1 in Fig. 3. This link confirms the argument that an increase in performance attributed to the use of innovations leads to additional innovation effort by relating behavior with outcome (Repenning 2002). The team member-driven motivation tends to have a higher impact when innovation efforts and successes are properly acknowledged and rewarded (Mitropoulos and Howell 2001).

In addition, perceived organizational climate for innovation in terms of resource supply and support for innovation can significantly motivate team members and consequently influence their innovation efforts. Indeed, the previous research has shown that it is not the availability of ideas that hinders innovation in construction but the decision to use them or the environment that influences them (Nam and Tatum 1992b).

<< Insert Fig. 3 about here >>

Earlier, we discussed how the championing behavior of PM affects innovation process. At the more detailed level, the championing behavior is influenced by individual factors. The individual factors considered in the model are the PM's experience and academic qualification, and personality-related behavioral dimensions, risk-taking attitude and innovativeness. Furthermore, it has been reported that knowledge gained from experience in previous projects and education of champions is important (Tatum 1987; Nam and Tatum 1997). Such knowledge helps to overcome the risk and uncertainties that innovation may bring. Researchers also suggest that championing role must be linked with entrepreneurial function. This includes risk-taking (Nam and Tatum 1997; Maidique 1980; Greenberg and Baron 1993) for success of innovation. It is further argued that PMs who are willing to take reasonable risks while securing project objectives foster innovation.

Another important factor that may also affect innovation process is the PM's innovativeness — a cognitive style that is an individual's propensity to innovate and thus represents PMs' preferred style of problem solving and decision-making (Kirton 1976; Goldsmith 1984). On the basis of the literature, it can be inferred that champions have high innovative orientation. Thus, a high level of innovativeness should be associated with higher levels of championing behavior. The individual variables discussed thus far are likely to influence PM's championing in the ways as shown in Fig. 4.

<< Insert Fig. 4 about here >>

Besides individual factors, there exist many situational factors that may influence the innovation process. As shown in Fig. 5, the generation of ideas is influenced by the level of subcontracting, size and complexity of the project, as well as size and competency of a project team. The latter factors influence the model framework, in particular, the volume, novelty, and scope of innovative ideas to be generated during the construction project period. It has been well recognized that the project in which a company engages offers an internal source of new ideas (Winch 1998; Nam and Tatum 1992a) because technical challenges on a construction project would demand innovative methods for improved performance. Nevertheless, idea generation largely depends upon the competency of project team members that can be traced to the domain-related and creativity-related skills. On the other hand, a higher level of subcontracting is believed to induce a few opportunities for innovation in the project (Langford and Male 2001), probably because this may create significant coordination and integration problems.

<< Insert Fig. 5 about here >>

In addition, organization-related situational factors such as decision authority given to a PM, resource supply, support for innovation, and support from owners and designers influence the implementation stage of innovation. As evident, a construction project involves many different parties with conflicting objectives; new ideas often receive strong resistance, making implementation of such ideas difficult (Nam and Tatum 1992a). Apparently, the successful implementation of construction innovation requires convincing several different stakeholders such as regulators and designers to allow the use of innovation (Tatum 1987).

Moreover, as the implementation of new construction methods or technology may be risky process, the innovation needs to be supported by key project stakeholders. As mentioned earlier, PM's championing role can facilitate the implementation of ideas by garnering support from various project participants. The success of an innovation is also attributable to the PMs' decision authority as PMs' involvement in making decisions about work done on site tends to motivate PMs by raising the level of responsibility, thus helping to expedite the implementation process.

All the causal loop diagrams discussed thus far are integrated to form the dynamic innovation model in Fig. 6. In the following sections, the model is qualified, using the survey results. The implications of the research are then discussed.

<< Insert Fig. 6 about here >>

Model Qualification

The dynamic innovation model described thus far consists of soft and hard variables. To give more reality to the model structure, measurable model variables were quantified using the questionnaire survey. Following a brief discussion on the framework used to measure key model variables, we assess the causal relationship among the variables.

Measurement Framework

The framework to measure important model variables is presented in Table 2. This framework was incorporated into the survey conducted in this research. Using questionnaires, we collected the necessary data from 32 PMs and 94 project team members working in 32 construction projects in Singapore.

<< Insert Table 2 about here >>

Assessing Causalities

Causal links can be established in a number of ways including direct observation, reliance on accepted theories, hypotheses or assumptions, and statistical evidences (Coyle 1977). In this paper, we establish the causal relationships of the model variables by assessing correlations between the associated variables. The data collected from the survey was analyzed, using the statistical software SPSS 11.0, and the bivariate correlations were calculated. The analysis generated the correlation coefficients as shown in Fig. 7.

Although most of the relationships presented in Fig. 7 do not directly represent the relationships among the variables in the model, the observed correlations provide sound support to the model through mediated relationships. In fact, many soft variables included in the model can be viewed as mediators. The indirect relationship of X on Z (through Y) can be diagrammed as $X \rightarrow Y \rightarrow Z$. There are at least two interpretations of such a relationship. First, Y may be viewed as a mediator of $X \rightarrow Z$ relationship such that the effects of X on Z are completely mediated by Y. For example, the higher performance gap causes the PM-driven motivation to increase, which in turn causes an increase in the PM’s championing behavior. Second, X affects Y and Z directly. For example, in our model, championing behavior causes an increase in both the generation of new ideas and implementation of the ideas directly. One of the conditions for mediator test is that X and Z are significantly related (Kelloway 1998).

The correlation results generally support the causal relationships hypothesized in the innovation model. The PMs’ working experience in the construction industry and with the company and PMs’ academic qualification significantly influenced their championing behavior. The positive correlation between innovativeness and PMs’ championing behavior supports the link as hypothesized in the model. However, the non-significant relation between the two seems to suggest that PMs are innovative in a narrow range, seeking minor improvements, operating within present practices and procedures or initiating changes that lie near organizational practices, and pushing boundaries incrementally.

The results indicated that several situational factors were significantly positively related to the level of innovation on the projects. The positive correlations of the level of innovation with size of a project team, project duration, project complexity, and contract value reflect the number of opportunities to innovate, as well as the opportunity to benefit more from a particular innovation on a project. However, contrary to our expectation, the positive correlation between subcontracting and the level of innovation is probably due to the suppression effects of other variables. As can be seen, resource supply, support for innovation, decision authority of the PMs, and PMs' championing behavior were positively related to the level of innovation which in turn was related positively to project performance. Overall, these results directly and/or indirectly support the model framework.

MODEL DISCUSSIONS AND IMPLICATIONS

A good understanding of the dynamic innovation process is a prerequisite for fostering construction innovations. In this paper, we explained the construction innovation process from a holistic perspective. We also identified the individual and situational factors that could foster or inhibit innovations. The dynamic features of the model accompanied by these factors provide a number of policy implications for practitioners.

PM's championing role and its importance may vary depending on project performance, which is mainly governed by the interaction between instrumental motivation and normative pressure. As discussed, when the actual performance does not reach the planned performance, PM-driven motivation dominates the innovation process. This fact indicates the importance of the PM's championing role in innovation that may increase with performance problems. On the other hand, team member-driven motivation becomes dominant, in which PM should be able to act as a facilitator rather than a pressure agent. Thus, PM should understand the project environment and context, the ability and a willingness of the team members before choosing an appropriate leadership style.

PM as a champion can convince and sell merits of innovation to potential project allies, coordinate them, and get necessary support and approval from them in order to facilitate the implementation of internally generated and/or imitated ideas in the project. Moreover, it is in the best interest of an organization to recognize the innovation opportunities in a particular project and the drivers and motives of project participants in order to create an environment that would unearth the innovative behavior of the project participants. This may require that organizations restructure the environment and/or programs to facilitate innovation on site without sacrificing project objectives.

A PM also needs to focus on enhancing the competency of project team members. This is because most project-related situational factors such as size and complexity of the project, subcontracting, and size of the project team are beyond the PM's control, although they are more or less correlated with the level of innovation in a project. At company level, policy priority should be given to recruitment of qualified personnel and enhancing their professionalism by providing training programs.

The significance of "resource supply" and "support for innovation" factors in innovation, as indicated in the survey results, implies that project team members can be motivated to enhance the level of innovation on site by adequate provision of resources and support for innovation. The analogy from the model structure also implies that this is even more evident i.e., when the project performance is better than the planned performance. Therefore, senior management should provide moral support and show evidence of its commitment to innovation, commit necessary funds, materials, information, time, and personnel to foster innovation and, view any change as an opportunity for improvement not as a risk. The supportive organizational climate in construction may also include acknowledgement of and reward for creativity; tolerance of risk, failure, and mistakes; culture that values innovation and change; and clear strategic vision of the company, among others.

In addition to sustained support from an organization, providing autonomy and decision authority are also important for the successful implementation of innovation, which is confirmed by the model as well as previous research (Nam and Tatum 1997). Thus, the organization should delegate enough authority and power to the PMs so that they have sufficient control on the project. For the same reason, the owner of a project needs to be flexible in sharing part of the risks to promote the level of innovation.

CONCLUSION

Previous research on construction innovation has commonly recognized the importance of organizational climate and key individuals' role. However, it has rarely focused on the role of project participants at the project level and addressed the dynamics of the construction innovation process. To address these issues, this paper presented a dynamic innovation model that has been developed using the concept of SD.

The model incorporated the various individual and situational factors believed to have influence on construction innovation. Focusing on project performance and organizational climate, we demonstrated how PM-driven motivation through the PM's championing behavior and team member-driven motivation facilitated by organizational climate for innovation would influence the innovation mechanism. Then, based on the model structure and the survey results, we discussed model implications to help foster construction innovations during the execution of the project. Although the research findings need to be further validated, the dynamic innovation model presented in this paper has provided common understanding and insights to the practitioners and researchers in order to foster innovations in construction.

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Table 1. Denotations for Causal Loop Diagramming (Sterman 2000)

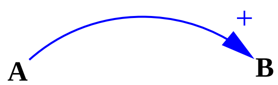
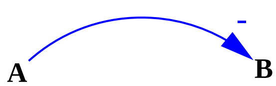
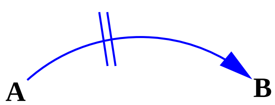
Types of causal links	Denotations
	All else remaining equal, an increase (decrease) in the variable ‘A’ increases (decreases) the variable ‘B’ above (below) what it would otherwise have been.
	All else remaining equal, an increase (decrease) in the variable ‘A’ decreases (increases) the variable ‘B’ below (above) what it would otherwise have been.
	A significant time delay is involved in implementing the causal relationship between the variable ‘A’ and ‘B’.

Table 2. Variables Measurement Framework

Variables / factors	Measurement framework
Experience	Experience factor was assessed, using the time spent in the construction industry, the present company, and as a PM.
Academic qualification	It was measured as the highest academic degree PMs had earned.
Innovativeness	PM's innovativeness was measured, using 32 items of the Kirton Adaptation-Innovation Inventory (Kirton 1976) on a five-point Likert scale.
Organizational climate for innovation	It was measured using 22 items developed and validated by Scott and Bruce (1994) on a five-point scale. This measure has two dimensions, namely, support for innovation and resource supply. The former was assessed with 16 items measuring the degree to which individuals viewed the organization as open to change, supportive of new ideas from members, and tolerant of member diversity. Meanwhile the dimension resource supply was assessed with six items measuring the degree to which resources (i.e., personnel, funding, time etc.) are perceived as adequate in the organization.
Decision-making authority	It was measured on the basis of the scale developed by Dulaimi (1991) by asking PMs to indicate the degree of influence they have in decisions made about the work on their site on a scale of 1 (virtually no influence) to 5 (a very great deal of influence).
Project characteristics	Project characteristics were assessed through a series of questions related to the *size of the project* (in terms of *contract value* and the *duration of the project*), the *size of the project team*, the *number of subcontractors* involved, and the *complexity of the project*. The latter was measured as the perception of the PM of the complexity of the project on a scale of 1 (not complex at all) to 7 (very complex).
PM's championing behavior	It was assessed by asking project team members to rate their PM's championing using 33 items on a scale of 1 (not at all) to five (frequently). The authors adopted 13 items from the work of Howell et al. (1998) and added additional 20 items to the construct in order to cover a more comprehensive aspects of PM's championing behavior.

Project performance	Project performance was assessed using 12 subjective measures as to the extent project team members perceived the project to have satisfied a particular criteria on a scale of 1 (not at all) to 5 (a great deal).
Level of innovation	It was measured by three items developed by Lewis-Beck (1977) to assess the innovativeness of the project. The items include statements to the extent that the project has utilized the most adequate equipment and materials; new construction methods or techniques; and the application of new ideas in the planning, organizing, and management of work on site on a scale of 1 (strongly agree) to 5 (strongly disagree).

List of Figure Captions

Fig. 1. An example of causal loop diagram

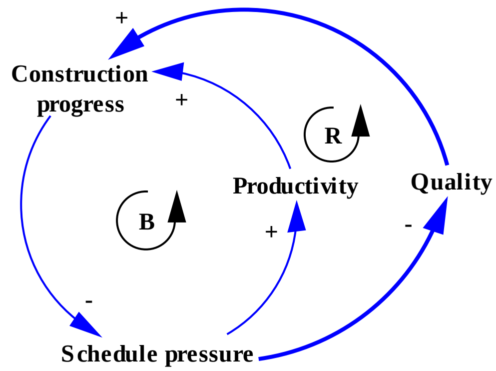


Fig. 2. PM-driven motivation

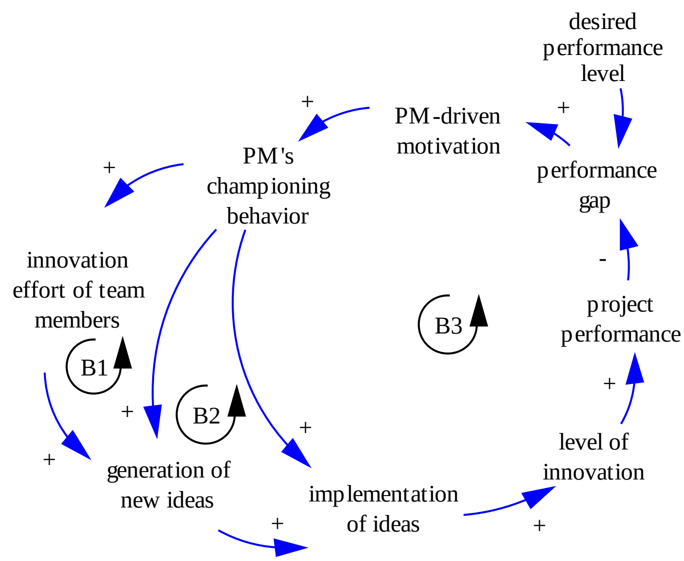


Fig. 3. Team member-driven motivation

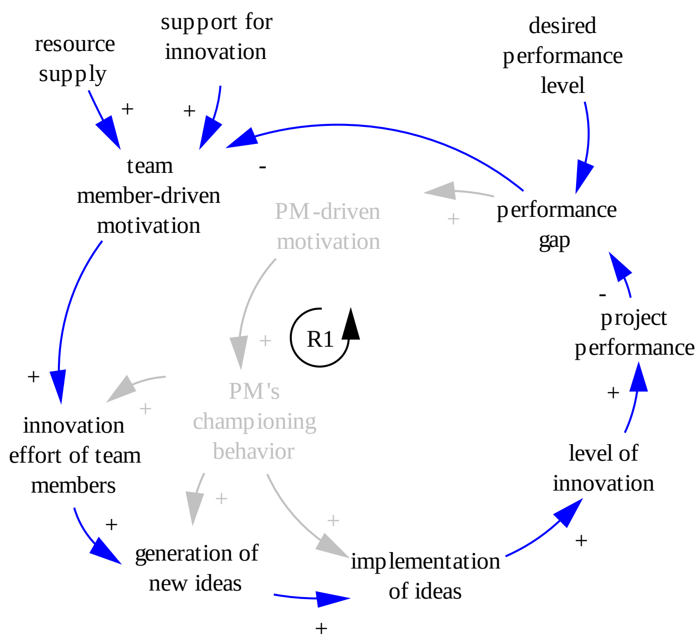


Fig. 4. Influence of individual factors on PM's championing behavior

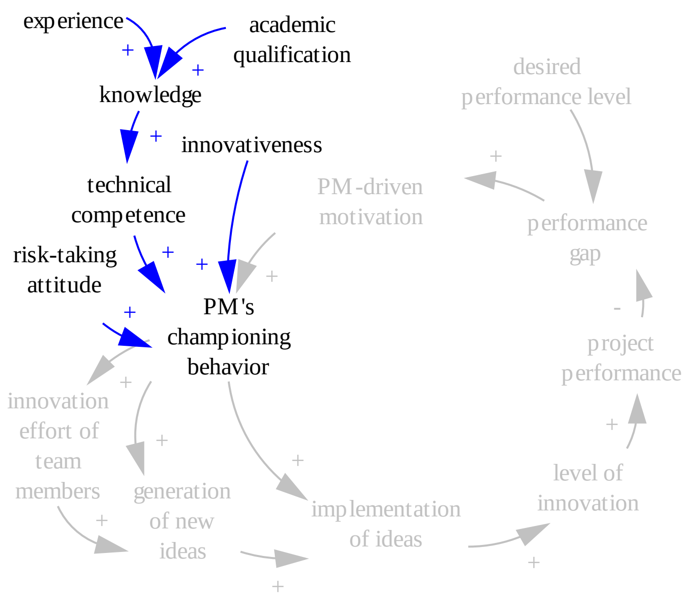


Fig. 5. Influence of situational factors in the innovation process

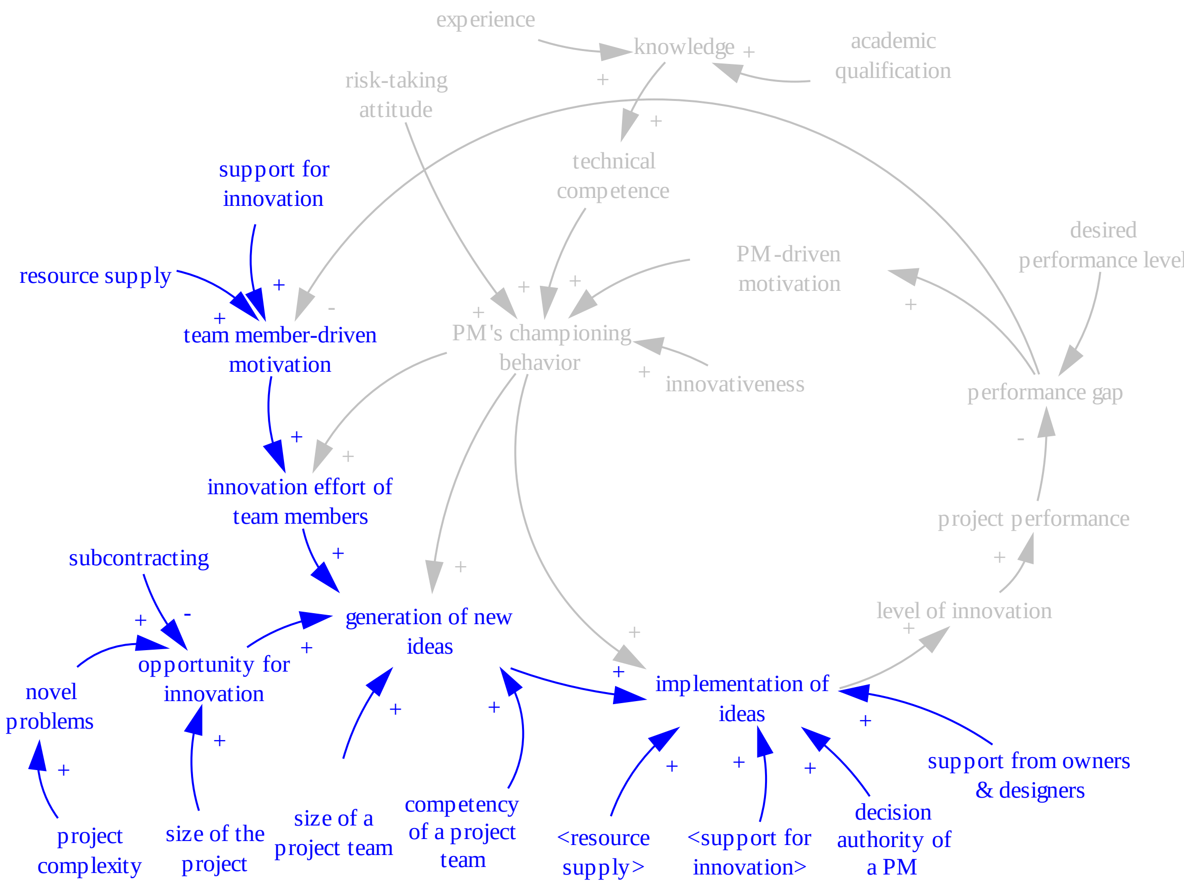


Fig. 6. Dynamic innovation model

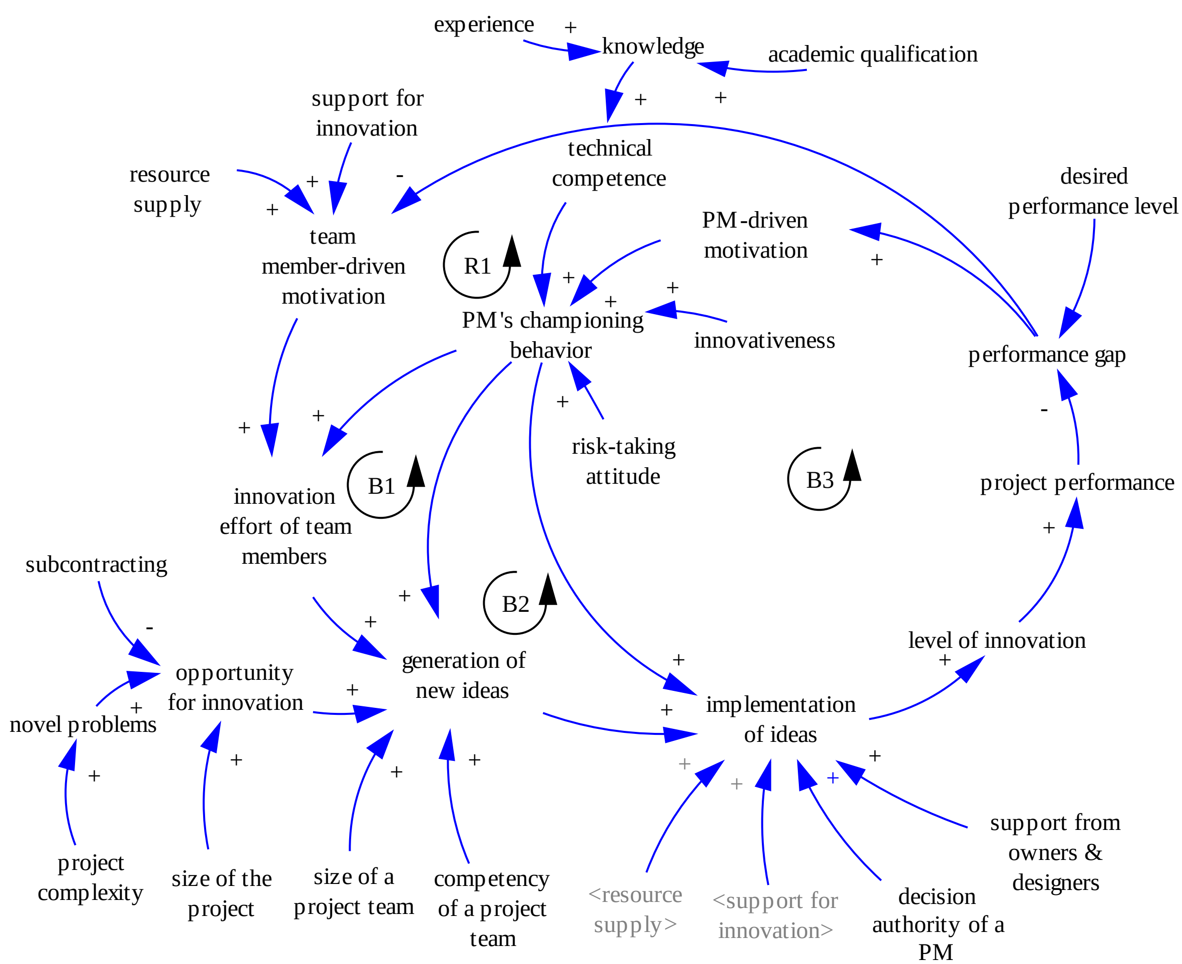
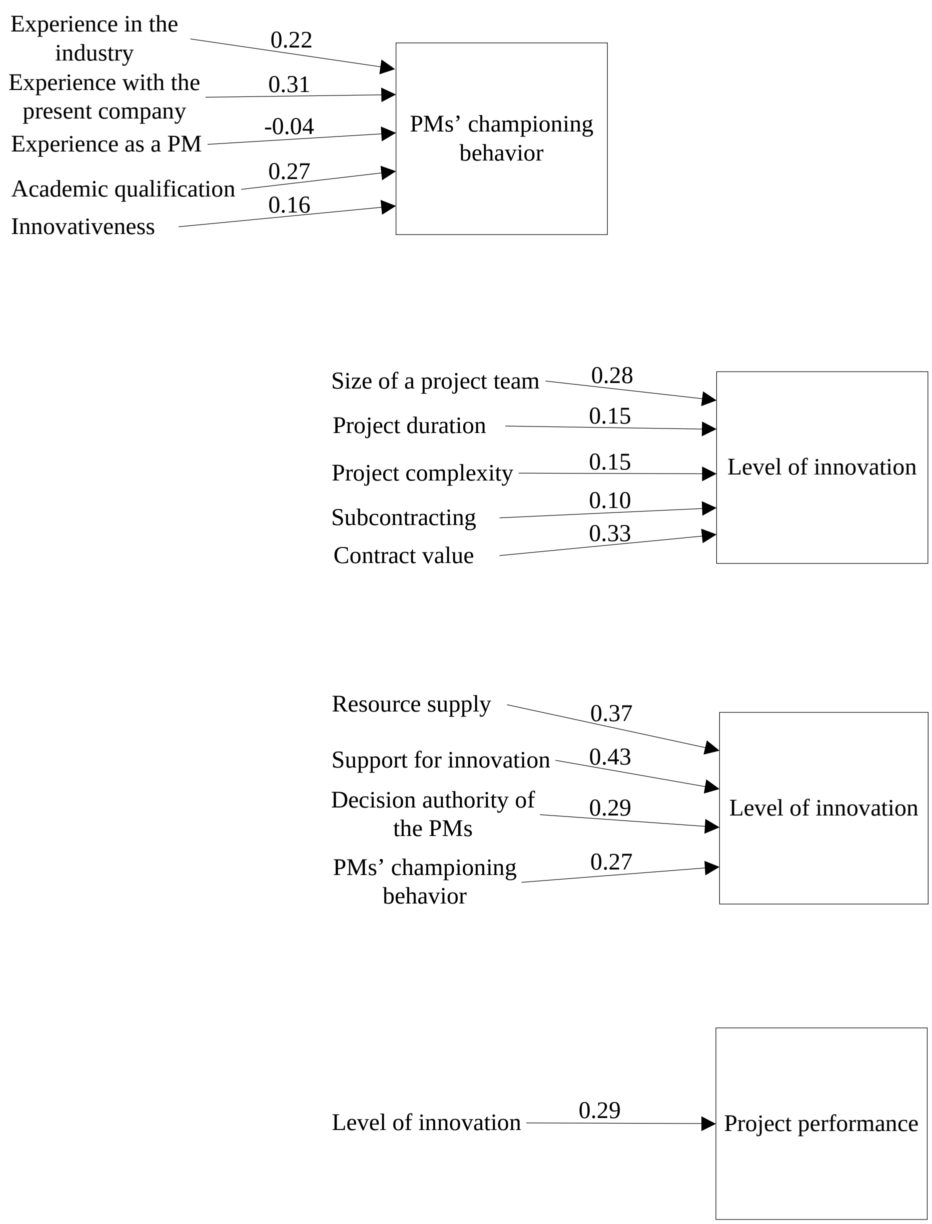


Fig. 7. Correlations among the model variables



Note: Correlations with an absolute value greater than 0.20 and 0.27 are significant at $p < 0.05$, and $p < 0.01$ respectively.